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RAINFALL AT OXFORD FROM 1767 TO 1814, ESTIMATED FROM THE RECORDS OF DR THOMAS HORNSBY AND OTHERS

By J. M. CRADDOCK and EVELINE CRADDOCK
(Climatic Research Unit, University of East Anglia, Norwich)

SUMMARY

An account is given of an examination of the surviving meteorological records made by Dr Thomas Hornsby, leading to the estimation, from this source and from other evidence, of monthly rainfall totals for the Radcliffe Observatory for the years from 1767 to 1814, linking with the Radcliffe instrumental record which has continued from 1815 to the present day.

1. INTRODUCTION

The record of meteorological observations made at the Radcliffe Observatory, Oxford from 1815 onwards is the longest and probably the best documented of any for a single site in Great Britain. This attempt to extend the record backward into the past began as part fulfilment of a contract made with one of us (J.M.C.) by the Natural Environment Research Council to produce homogeneous rainfall records for as far back as the evidence will justify. Each district presents problems of its own, and for the Oxford area there is a clear distinction between the period from 1815 onwards, for which there is an almost complete series of daily observations to the present day, and the period before 1815, for which the evidence is fragmentary, incomplete and often indirect. This paper deals with the early period in which the direct evidence consists almost entirely of the surviving manuscript records of Dr Thomas Hornsby. These records, which are now kept in the Library of the School of Geography at Oxford, were made by Dr Hornsby for his own use, and lack most of the information on units, sites and instruments which should appear in a record intended for publication. There are gaps where Hornsby failed to take the observations, gaps where some of his original records have been lost, and incredible readings which have to be replaced by reasonable estimates. Nevertheless, the authors feel that the series of estimated monthly rainfall totals for the Radcliffe Observatory site will bear comparison with those for the years after 1815, and the paragraphs which follow provide the justification for the values offered for the years from 1767 onwards. The investigation falls into two parts:

(i) The interpretation of Dr Hornsby's manuscripts and the conversion of his figures into modern units familiar to the readership, and

(ii) The estimation, from this and other evidence, of what would have been caught in each month from 1767 to 1814 by a modern rain-gauge with rim 1 ft above ground in today's observing site at the Radcliffe Observatory.

These steps we carried out in order, and when the first stage was complete, we sent copies to Professor Gordon Manley, Mr C. G. Smith of Keble College, Oxford and Mr B. G. Wales-Smith of the Meteorological Office for information and comment. Professor Manley provided a copy of a rainfall record made at Shirburn Castle, about 12 miles from Oxford, which was previously unknown to us, and more recently Mr C. G. Smith has provided us with the results of his own researches into sources in Oxford, including a revised version of the Shirburn record, which confirm our main inferences. Mr Wales-Smith has provided data for stations around Oxford which form the basis for our estimates for the years for which credible measurements at Oxford or Shirburn are lacking.

2. The background

According to the Dictionary of National Biography, Thomas Hornsby was born in Oxford in 1733. C. G. Smith, in a private communication, states that he entered Corpus Christi College, Oxford in 1750, took his B.A. in 1753 and his M.A. in 1757. By the next year Hornsby must have met the Revd William Borlase (1695–1772), rector of Ludgvan, near Penzance, whose 'Natural History of Cornwall' was published in Oxford in 1758. It is not clear how they met, and developed their interest in rainfall measurements, but Borlase, who was elected a Fellow of the Royal Society in 1750, and who had started his own weather record on 10 January 1753, consulted Hornsby on the design of an 'ombrometer', or rain-gauge. Much of Borlase's correspondence has survived in libraries in Cornwall, and extensive extracts have been quoted by Oliver (1969). Dated letters establish the development of Hornsby's ideas on rain-gauging. Hornsby was elected a Fellow of Corpus Christi College, and in 1761 he observed the transit of Venus at the private Observatory of the Earl of Macclesfield at Shirburn Castle. This observatory was set up in about 1739 with the advice of James Bradley, the Savilian Professor of Astronomy. In 1763 Hornsby was elected a Fellow of the Royal Society, and in the same year he succeeded Bradley as Savilian Professor. It seems that Hornsby must have married at about this time, since his elder son was born in 1766, and on marrying he would have had to vacate his college rooms. He must have occupied the house which from the time of Edmund Halley had been leased by New College to the University for the Savilian Professor and this is the most likely site of the rain-gauge he used from the year 1767. Borlase, writing on 27 July 1767, commented that Hornsby's situation was 'much surrounded by buildings and walls', a state liable to affect his meteorological observations, and it seems that his house was not ideal for astronomical observations either since, according to C. G. Smith, Hornsby observed the transit of Venus on 3 June 1769 from the Tower of the Schools (Bodleian Library). In 1772 Hornsby was appointed to be the first Radcliffe Observer, and laid the foundation stone of the Radcliffe Observatory in the same year. It seems that the main Observatory building was largely complete by 1779 although, because of shortage of money, the external decoration was not completed until 1794. However, the Observer's House was ready for occupation by

1776, and it may be that the burden of moving house, added to Hornsby's other commitments, led to the cessation of his rainfall observations in that year. The building and the telescopes, which were the finest of that time, included two quadrant instruments, and the total cost was £28 000, a figure which may be compared with Bradley's stipend as Savilian Professor, which was £100 per annum. In 1782 Hornsby was appointed Sedleian Professor, a post which made heavy demands on his time, and in 1783 he became Radcliffe Librarian. Five papers by him were read before the Royal Society, at dates between 1763 and 1773, while several sources suggest that his courses of lectures gained considerable renown. He had also undertaken to edit Bradley's 'Astronomical Observations' for the Clarendon Press, but because of ill health (he was epileptic) or more probably, sheer overwork, the first volume did not appear until 1798, after more than 20 years' delay. Hornsby died in Oxford in 1810.

3. The Hornsby manuscripts

These are the bare facts of a mainly astronomical career, but Hornsby's interest in meteorology must date from before 1758, when he informed Borlase of the dispatch of a rain-gauge. Hornsby's weather records, or at least the ones known to have survived, are contained in two ledgers and some loose sheets which are now kept in the Library of the School of Geography in Oxford. The ledgers contain many pages of what seem to be astronomical calculations, with some weather notes which appear to have been inserted later, as if the blank pages were being put to use after the books had served their main purpose. Most of the loose sheets seem to have been torn from similar books, although there is nothing to show whether this was done by Hornsby himself, or subseqently. Taken in order, the weather notes cover the year 1760 and part of 1761, then an almost complete daily record for 1767 to 1776, and another from July 1794 to 1805. There is also a single loose sheet on which Hornsby has extracted the annual rainfall totals for 1795 to 1802, but also gives totals for the preceding years 1785 to 1794, and other sheets on which some of the monthly rainfall totals for years between 1795 and 1802 are summed to obtain the annual totals. These appear to be rough working sheets. The entries consist mostly of the date and time, followed by the barometric pressure and the temperature, the wind direction, and the rainfall, if any, and finally the state of the weather. Occasionally notes and phenological observations are written across the columns, but with these exceptions, there is nothing to explain how the observations were taken, and the units in use have to be deduced from occasional initials above the columns, from a few conversion tables which Hornsby obviously made for his own use, or from the observations themselves. With the agreement of Mr C. G. Smith, we visited the School of Geography several times, and examined the Hornsby manuscripts minutely, with the results to be described. Hornsby, as an astronomer, was used to carrying out calculations to a great many places of decimals, a habit that is most necessary in astronomy—which after all, was his main preoccupation—but rather out of place in meteorology. However, we should remark that while we carried out our work with the help of modern technology, such as electric light, motor transport, ball-point pens and electronic calculators, Hornsby probably had to manage with candles, a horse, quill pens and his own skill in calculation, so that the question we constantly had to ask ourselves was 'What would an intelligent man do in this situation, with the resources at his command?'.

4. A GOOD LOOK AT THE RECORD

As mentioned already, the record falls into three parts, as follows:

(i) The first part starts in January 1760 (or at least, the part which has survived does so). This is obviously the work of a young and inexperienced man, because, while the writing is firm and neat, the entries show that Hornsby was not sure what he was looking for. This part includes measurements of rain, which, in all probability, were made with the rain-gauge of 3 inches square, referred to in the correspondence between Hornsby and Borlase mentioned by Oliver (1969). This gauge led to a pipe which descended from the roof into a collecting vessel in his room, a system used earlier by Towneley (1694) and Derham (1698), as well as in the later record at the Radcliffe Observatory from 1815 until 1879.* It is a fair inference that Hornsby made all his rainfall measurements with instruments of this kind, though not necessarily in the same place, or with collecting vessels of the same dimensions or pattern. The observations are kept regularly during 1760, but become scrappy in 1761, and peter out in March.

(ii) The observations in 1767 show all the signs of being a fresh start. They start at the beginning of the year, at the top of the page, and continue without much change of content. Evidently, by this time Hornsby had decided what his observing routine was to be, and intended to keep to it. His pages were ruled by hand, and some years are in the bound ledgers, in what appear to be the pages left unused after his astronomical calculations. There are two or three observations per day, with hardly any gaps, although there are two or three places where he has not formed a monthly total from his daily values on account of his having spent part of the month at 'Sherburn'. From 1769 there are some gaps during the summer, including one when Hornsby made the considerable journey to Ludgvan to visit William Borlase on 28 July 1770. From 1775 there are plain signs that Hornsby, though still maintaining the content of his record, was suffering from overwork. There are spaces left for results which have never been worked out, and in 1776 the register comes to an abrupt halt, without explanation.

(iii) The third section of the register probably started at the beginning of 1785, although the part preserved in the Hornsby manuscripts starts in July 1795. The reason for thinking this lies in the single sheet on which Hornsby, in about 1803, listed his annual rainfall totals, presumably in the hope of seeing whether they followed any recognizable pattern. There is no trace of the daily workings or monthly summations for 1785 to 1793, but the sum for January to June 1794 is carried from another sheet, now lost, and added to the actual total for the months July to December, for which the daily records have survived. It is reasonable to think that daily entries once existed for the whole period 1785 to June 1794, perhaps in another ledger. Hornsby must have known the year in which he resumed his observations, and would hardly have headed his sheet with 1785 if there had been no data for that year. This point is emphasized for the reason discussed in section 8, that he seems to have missed out one of his annual totals. Hornsby's handwriting changes over the 45 years covered by these records, and by 1805 was that of a very old man, who found it a burden to put

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* *Note.* Another rain-gauge at ground level was also used from 1851.

pen to paper. There is no terminal paragraph, like that with which Samuel Pepys ended his diary, but Hornsby's entry in August 1805 suggests a man at the end of his physical resources.

5. Making sense of the data

For the first period, January 1760 to March 1761, entries seem to have been made only on the days on which rain fell, the receiver being emptied after each fall. A typical reading for 29 January 1760 is 42·1 and for 18 February 1761 is 0 47¾ while the monthly totals range from 0 49¼ to 3 03. There is no indication of the units used, but Hornsby's monthly totals agree with the constituent daily figures only if his larger unit is 72 times the smaller. The explanation can be inferred from a letter to a third party (St Albyn) by William Borlase, who consulted Hornsby in matters of instrumentation. This is given verbatim by Oliver (1969) 'My vessel that receives the rain is exactly 3 inches square at the upper orifice, which being in number of 9, as soon as I have 9 inches in the tube or bottle, I conclude that (there is) one cubical inch of water in the area of one square inch. The collecting vessel was of tin and was made for me in the year 1758 by the Revd Mr Hornsby, now Savilian Professor at Oxford from a pattern which he made use of in his own apparatus'. This implies that the measuring vessel was of 1 square inch in cross-section, and at least 9 inches deep, so that unless it had a glass insert, it must have been very difficult to read. Probably Hornsby decided very soon that he must find a better solution to the problem of measurement. Writing on 17 October 1758, he described the construction of his own rain-gauge, and explained how, by pouring into his measure known quantities of water, he could graduate it first into 9 one-inch divisions, each equivalent to 1/9 inch of rain, and then 'by eye' subdivide these into 8, so that he could measure to a scale accuracy of 1/72 inch. These extracts imply that the first section of Hornsby's record started in the year 1758 if not earlier. It is also noteworthy that the directions will apply to the graduation of any glass tube of reasonably constant cross-section, and it seems likely that Hornsby, like Borlase, used a graduated glass tube reading directly in inches. There may be more information in his original letters, if these are included in the volumes of Borlase's correspondence which have survived, since Oliver (1969), who provides the extracts, was interested in Borlase rather than Hornsby. We hope to work through Borlase's original correspondence at a later date. On 18 June 1767 Hornsby wrote to Borlase suggesting that it was best if rain-gauges were graduated by weight 'using a hydrostatical balance on the assumption that a cubic inch of rain weighed 253 grains'. These facts enable his early readings to be reduced to inches in Table I.

Table I—Monthly totals recorded in 1760 and 1761, in inches, not corrected for elevation of gauge

	J	F	M	A	M	J	J	A	S	O	N	D	ANN
1760	1·03	1·47	0·52	—	1·29	1·62	0·21	0·23	1·53	2·34	0·75	1·00	—
1761	0·03	0·85	0·67	—	—	—	—	—	—	—	—	—	—

These observations were probably made by Hornsby in his college rooms (of which the exact location cannot be determined from the College records), with the collecting funnel of the rain-gauge above the roof; a loss of catch of at least 10 to 20 per cent seems probable, compared with a modern gauge in a standard exposure.

6. Problems of site and measurement

When Hornsby resumed his record in 1767 he must have been living in the house provided by the University for the Savilian Professor, and probably had his rain-gauge there. The record starts in January 1767 with what looks like a burst of enthusiasm, but soon settles down to a regular routine. It seems that the rain was measured after each considerable fall, and the units look puzzling, as the columns, which usually are not headed at all, are sometimes headed 'inches' and 'pwt'. A typical entry is 0 34¾ for 13 February 1767, and comparison between daily and monthly totals soon shows that the smaller unit is now 1/36th part of the larger. Evidently Hornsby graduated his measuring cylinder to read directly in inches of rain and thirty-sixths. At the end of July 1767 he notes 'On 30th I found that the rain from a fault in the tiling came into the room on the outside of the tin tube, and from thence into the glass. I therefore had a piece of tin put on yesterday in order to prevent it in future. In hard rains I fear this has happened before, particularly in June—perhaps in January and February'. This extract supports the description of the gauge which he gave to Borlase in a letter dated 3 March 1767. Hornsby continued with these units, apparently until January 1775, but then comes a very important change, without any comment, because the entry for February 1775 reads:

	lb	oz	dwt	gr
Weight of rain and glass	9	3	4	10
Weight of glass	3	11	6	21

7. The final choice of site and gauge

From this date until September 1776, the entries are by weight, with conversions into inches in most months. A typical entry, for October 1775, is 10 0 21 6 = 2·462460. These entries show that the equivalence of one inch of rain is a weight of just over 4·09 lb, whereas with a circular rain-gauge of 12 inches diameter, one inch of rain weighs 4·0906 lbs. The use of a measuring cylinder of 1 inch cross-section is clearly not a practical proposition with a rain-gauge of this size, but it is interesting to find, among the records, a scrap of paper which suggests that Hornsby took the trouble to investigate the matter. This scrap bears a calculation, without heading, which finds how long such a cylinder would have to be if it was to measure up to 12 lb of water. The answer comes to nearly 7 feet, so perhaps Hornsby envisaged himself grovelling on the floor, or climbing a ladder, to measure his rainfall, and decided to stick to measurement by weight. The appearance of a 12 inch circular gauge in 1775 is very significant, since the building of the Radcliffe Observatory started under Hornsby's direction in 1772, and after two years some of the rooms must have been fit for occupation. The gauge on the East Wing of the Observatory, which was in regular use from 1815 up to 1879, was of this diameter, and had a tube leading from it to a receiver in the quadrant room, which would have been needed for two of the telescopes installed by Hornsby, so there is a strong probability that the gauge installed by Hornsby in 1775 was left in place after he stopped making observations in 1805, and brought back into use again in 1815. Support for this view exists in the form of some intermittent observations dating from 1811, until the continuous record was resumed, actually in April 1814. We are indebted to Mr C. G. Smith for a reference to Gunther (1923) who states in a footnote 'On Dec. 31, 1774 P. and J.

Dolland supplied a copper funnel for a pluviometer for £2 12s 6d'. Rigaud (1835) describes a copper funnel which, if our inference is correct, is the same funnel, as having a mouth 12 inches in diameter and a depth of 10½ inches and gives its exact position above the East Wing of the Observatory. This must be the gauge which continued in use until 1879, and was replaced by Knox-Shaw and Balk during the 1920s to estimate the factors needed to correct the readings to modern standards. These factors are discussed in section 10, but a mean factor for all months of 1·130 seems adequate. Values as observed up to 1776, without correction for exposure etc. are given in Table II.

TABLE II—MONTHLY TOTALS FROM JANUARY 1767 TO SEPTEMBER 1776

	J	F	M	A	M	J	J	A	S	O	N	D	ANN
1767	(5·12)	(5·13)	1·72	0·55	3·13	5·81	(5·76)	2·92	2·20	3·56	0·86	0·24	(37·00)
1768	2·14	1·95	0·13	2·49	1·23	4·13	2·40	1·25	5·35	3·31	2·66	2·16	29·21
1769	1·08	1·64	0·85	0·61	1·79	2·78	—	—	—	0·43	1·71	2·05	—
1770	0·63	0·90	1·89	0·76	1·88	2·95	0·60	(0·84)	—	0·76	6·02	2·33	—
1771	0·43	0·71	1·16	0·76	0·68	2·06	0·90	1·97	(0·69)	3·29	0·42	0·89	13·96
1772	3·05	2·80	2·33	1·24	1·42	1·22	0·97	2·26	3·88	2·72	5·19	1·01	28·09
1773	0·97	0·49	0·35	1·46	4·85	0·81	0·98	2·53	2·51	1·39	3·93	1·63	21·90
1774	2·78	2·03	2·77	0·49	0·35	1·27	1·38	2·11	7·01	0·35	1·28	(0·00)	21·82
1775	2·25	1·34	2·21	2·48	1·26	2·54	1·29	4·36	4·64	2·46	2·27	0·09	27·19
1776	(0·00)	2·89	2·09	0·29	0·89	3·46	2·35	3·83	1·79				

8. A PROBLEM OF COPYING

As mentioned in section 4, Hornsby seems to have been suffering from overwork in 1776, which is not surprising in view of the number and variety of his commitments, and Mr C. G. Smith points out that he also had the burden of a domestic removal, since the Radcliffe Observer's house was ready for occupation in that year, and the minor annoyances inevitable when working in a partly finished Observatory building. This probably explains why he stopped making his rainfall observations, and did not resume until 1785. The evidence for this resumption lies in a single sheet of paper on which, in about 1803, he extracted the annual totals from 1785 on. It seems that he wrote the year numbers first and then the yearly totals, because it happened that the annual totals for 1794 and 1795 were very much alike, and that he got the preceding totals one year out of step. However, the mistake can be corrected, by reference to some of his monthly summations and to the annual totals recorded at the closest neighbouring stations, Stroud and Shirburn. Comparative annual totals are given in Table III (a) and his monthly totals from 1795 to 1805 in Table III (b).

9. HOMOGENIZATION—THE RELEVANT EVIDENCE

The investigation has so far described what was actually observed by Dr Hornsby, and has given in inches of rain what he measured with several rain-gauges in different situations. To produce figures for the period 1767 to 1814 which are comparable with the measurements being made at the Radcliffe Observatory today, conversion factors must be applied to Hornsby's data, and reliance must also be placed on evidence from some of the stations listed in Table IV. None of these stations is very close to Oxford, and it is not suggested that the daily rainfall at any of these stations would provide a good estimate of the rainfall at Oxford on the same day. Nevertheless, the ratios of annual totals at these stations to those at Oxford show a measure of constancy which is evident in Table III (a), and which can be expressed in numerical terms. The monthly variation of rainfall within the year also show a good deal of consistency over

TABLE III—MONTHLY AND ANNUAL RAINFALL TOTALS FOR OXFORD 1785–1805 AS GIVEN BY DR HORNSBY WITHOUT CORRECTION

(a) Annual totals 1785–94 (assigned to the right years)

	1785	1786	1787	1788	1789	1790	1791	1792	1793	1794
Hornsby	16·495	20·697	19·528	12·305	27·755	17·095	20·518	25·465	19·952	22·023
Shirburn	20·24	22·18	23·88	16·50	29·13	20·72	22·70	30·84	23·52	26·32
Stroud	24·13	30·88	29·64	18·51	37·99	26·23	30·04	34·06	28·41	27·57

(b) Monthly totals July 1794–August 1805

	J	F	M	A	M	J	J	A	S	O	N	D	ANN
1794							2·785	1·760	2·340	3·015	3·820	1·045	22·023
1795	0·450	2·095	1·860	1·590	0·045	4·885	1·845	1·975	0·210	3·785	1·735	1·740	22·215
1796	2·675	1·284	0·420	0·200	2·100	0·750	3·075	1·545	1·060	1·910	0·665	2·115	17·795
1797	1·330	0·280	1·600	1·325	1·175	3·775	2·275	2·490	5·088	0·850	1·880	2·950	25·018
1798	1·910	0·0930	0·410	1·515	1·610	1·020	4·325	0·800	2·085	3·670	3·935	1·030	23·240
1799	1·610	2·425	0·950	2·545	1·915	0·490	3·130	3·090	5·600	3·090	2·000	0·650	27·495
1800	2·480	0·470	1·470	2·500	1·750	0·580	0·040	1·120	2·705	2·370	5·350	2·155	22·990
1801	1·263	0·380	1·180	0·190	2·580	1·430	2·010	1·895	1·555	1·700	2·615	1·810	18·608
1802	0·320	1·805	0·240	0·240	1·565	1·585	2·995	0·225	0·255	1·430	1·500	2·075	14·235
1803	1·835	1·435	0·205	0·605	0·710	2·510	1·560	0·665	0·800	0·250	3·935	3·850	18·360
1804	2·580	0·595	2·830	1·850	1·935	0·525	3·155	1·860	0·290	2·675	2·380	0·755	21·430
1805	1·865	0·920	0·560	1·495	1·370	1·595	1·320	1·845					

the distances which appear in Table IV, and justifies the production of homogeneous monthly totals for Oxford. Our procedure is to find the ratios of corresponding annual totals for two stations for as many years as are available, and to examine the sequence and measure the interannual variability of these ratios. Where there is no apparent change in the ratio with time, and the interannual variability is small, then the mean ratio provides a conversion factor which can be applied to totals observed at one station to provide estimates for the other. This technique, which will be described in detail elsewhere, provides a very sensitive means of detecting faults in rainfall records and obtaining estimates for missing or incredible totals, provided that there are several overlapping records of reasonable length within a small area. The stations listed in Table IV are more widely spaced, fewer in number and more variable in quality than would be chosen by preference, but still are well within the area of significant association, which can be estimated from data for more recent years. We decided to keep our estimates independent of the long and important Lyndon record, and after considering all, relied only on Stroud, Lambeth and Sunbury to supplement Hornsby. The basis for our estimates for each year from 1767 to 1814 is given in Table V.

TABLE IV—RECORDS GIVING EVIDENCE ON OXFORD RAINFALL 1760–1814 (1916–50 AVERAGE FOR OXFORD IS 26·67 INCHES)

Station	Observer	Period	Bearing and distance from Oxford	1916–50 average *inches*
Stroud	Dr Hughes	1771–1773, 1775–1813	W 44 miles	33·58
Longleat	Jeremiah Cruse	1789–1799	SW 61 miles	35·13
Selborne	Gilbert White	1780–1792	SSE 46 miles	37·86
Odiham	?	1787–1789	SSE 44 miles	
Shirburn Castle		1780–1795	SE 12 miles	
Lambeth	Symons's MS.	1765–1782	SE 52 miles	23·42
South Lambeth	?	1782–1791	SE 52 miles	23·60
Sunbury	J. Cowe	1797–1838	ESE 43 miles	23·75
Lyndon	T. Barker	1736–1798, 1800	NE 64 miles	26·19
Kimbolton, Hereford	?	1781–1788	WNW 74 miles	

TABLE V—BASIS OF HOMOGENEOUS RAINFALL TOTALS FOR OXFORD FOR A STANDARD METEOROLOGICAL OFFICE GAUGE AT THE RADCLIFFE OBSERVATORY FOR 1767–1814

Years	Basis	Conversion factor	Notes
1767–74	Hornsby (Table II)	1·32	Missing months 1767–76 estimated from Lambeth
1775–76	Hornsby (Table II)	1·130	
1777–79	Stroud & Lambeth		Est. = Stroud × 0·3905 + Lambeth × 0·5674
1780–84	Shirburn Castle	0·977	
1785–94	Hornsby (Table III (a))	1·130	Annual totals divided between months in proportion to Shirburn Castle
1795–Aug. 1805	Hornsby (Table III (b))	1·130	
Sept. 1805–March 1813	Stroud × 0·3905 + Sunbury × 0·4922		
Apr. 1813–March 1814	Sunbury × 0·9844		
Apr. 1814–Dec. 1814	Oxford × 1·130		

10. ESTIMATION FOR THE YEARS 1775 TO EARLY 1805

The factor 1·130 applied to Hornsby's totals for 1775–76 and 1795–1805 depends on the inference made in section 7 that Hornsby's 12 inch gauge was in the same site as the rain-gauge used from 1815 onwards (and may indeed have been the same gauge). The correction of measurements made at this site has been discussed by Knox-Shaw and Balk, and their figures appear on page 95 of the Appendix to the volume of the Radcliffe Meteorological Observations for 1926–1930. They give a table of monthly factors ranging from 1·115 in August up to 1·150 in December and January, but the mean value of 1·130 for all months is probably as accurate as the data will justify. For the years 1785 to 1793, we have Hornsby's annual totals (corrected by the above factor), but no monthly totals, whereas at Shirburn Castle 12 miles away there are monthly totals from October 1779 to October 1795 which were certainly made with Hornsby's knowledge and probably under his direction. The original records are in the Bodleian Library (MSS. 26131–26159 under Savile MSS. 63 to 94) and the authors are grateful to Professor G. Manley and Mr C. G. Smith for sending them copies. An entry on the flyleaf states that a new circular funnel of 12 inch diameter was put on the 'ombrometer' on 15 September 1779, and that it emptied into a glass tube graduated to read directly in inches of rain and hundredths. Apparently the catch was measured every few days, presumably when the glass was nearly full, but as the total capacity was only 1·2 inches it could have been filled to overflowing in thunderstorms. Perhaps this explains Hornsby's calculations, mentioned in section 7, when he was considering the installation of his own 12 inch gauge and calculating the safe length for a tubular receiver. The Shirburn record seems to be deteriorating towards the end. A comparison between the Shirburn annual totals for 1785 to 1794 and Hornsby's corrected totals is given in Table III (a) and the reduction factor of 0·977, which brings the two 10-year totals into line, is applied to all the Shirburn monthly values.

11. Estimation for 1767–74 and late 1805–1814

The correction factor for Hornsby's record from 1767 to 1774, when he was using an older rain-gauge, may be estimated from the records at Stroud and Lambeth which extend both before and after the end of January 1775 when he changed his rain-gauge. However, the first step is to estimate totals for the months between 1767 and 1774 when Hornsby's values are either missing or incredible. This was done by means of the Lambeth record, the conversion factor for the wanted months in each year being found from the ratios of the totals at Oxford and Lambeth in the months with observations for both stations. These estimates have been inserted in Table II. For the months between August 1805, when Hornsby's record ceases, and April 1814 when the continuous record begins, there are odd months for which rainfall totals are preserved with the Hornsby manuscript in the Library at the School of Geography, Oxford. With some hesitation we have ignored these, and our estimated monthly totals from September 1805 to March 1813 are the average of estimates from Stroud and Sunbury, about equidistant from Oxford to west and east. The entire homogeneous series for 1767 to 1814 is given in Table VI.

12. Discussion

The rainfall observations at the Radcliffe Observatory, Oxford provide a fund of detailed information from gauges within a small area. These records can have few rivals in respect of the length of the period covered, and in the high proportion of original notes which have been preserved. For most years since 1851 measurements have been taken daily with a gauge, standard in construction and exposure, in a site within a few feet of that now in use. This is obviously the most reliable part of the record; for the years 1815 to 1850 only the 12 inch gauge with rim 22 ft above ground level on the East Wing of the Observatory was in use, and the correction of the readings of this gauge to modern standards involves the use of the monthly correction factors estimated by Knox-Shaw and Balk or more simply, their average factor of 1·130 used here. It must be emphasized that such correction factors can provide no more than an approximation to the truth, because when two rain-gauges at the same site are exposed to different wind regimes, as they are when the elevations are different, the gauge subjected to the stronger wind will catch relatively a lower proportion of the smaller droplets, and a higher proportion of the larger drops, so stability in the ratio of the catches can be expected only if these are measured over a period long enough to contain representative samples of wind speeds and drop sizes. The monthly and annual totals given in Table VI must be subject to errors which are larger than those in similar estimates based on modern data, but the method of reduction should ensure that these errors are randomly distributed and unrelated to one another, so that their effect is diminished when these data are used, for example, in comparisons with rainfall data for other parts of the British Isles etc., or for estimating rainfall totals for the seasons.

13. The significance of the Hornsby record

In a previous paper (Craddock, 1976) the evidence for the England rainfall of the 18th century was surveyed, and attention was directed to the break in the records around the year 1800, in that few observing sites which were in use for many years before then were also in use for long afterwards. The inference in the

TABLE VI—OXFORD HOMOGENIZATION

	J	F	M	A	M	J	J	A	S	O	N	D	ANN
1767	2·84	3·64	2·27	0·73	4·13	3·08	5·16	3·85	2·90	4·70	1·14	0·32	34·76
8	2·82	2·57	0·17	3·29	1·62	5·45	3·17	1·65	7·06	4·37	3·51	2·85	38·53
9	1·43	2·16	1·22	0·81	2·36	3·67	1·97	2·40	5·10	0·57	2·26	2·71	26·66
1770	0·83	1·19	2·49	1·00	2·48	3·89	0·79	1·08	2·68	1·00	7·95	3·08	28·46
1	0·57	0·94	1·53	1·00	0·90	2·72	1·19	2·60	0·91	4·34	0·55	1·17	18·42
2	4·03	3·70	3·08	1·64	1·87	1·61	1·28	2·98	5·12	3·59	6·85	1·33	37·08
3	1·28	0·65	0·46	1·93	6·40	1·07	1·29	3·34	3·31	1·83	5·19	2·15	28·90
4	3·67	2·68	3·66	0·65	0·46	1·68	1·82	2·79	9·25	0·46	1·69	1·86	30·67
5	2·54	1·51	2·50	2·80	1·42	2·87	1·46	4·93	5·24	2·78	2·57	0·10	30·72
6	3·80	3·27	2·36	0·33	1·01	3·91	2·66	4·33	2·02	0·90	2·24	1·94	28·77
7	1·20	1·49	1·76	1·93	4·51	2·94	3·33	1·51	0·74	3·77	1·43	0·91	25·52
8	2·60	0·79	1·11	0·83	1·83	1·95	4·19	0·10	1·26	2·89	4·09	3·17	24·81
9	0·43	0·46	0·57	1·88	2·27	2·61	4·86	1·44	2·45	3·12	2·81	4·98	27·88
1780	1·09	0·62	1·08	2·35	1·34	1·41	2·03	1·16	2·85	2·79	2·34	0·07	19·13
1	1·62	1·71	0·08	1·11	1·82	3·29	1·74	1·36	2·61	0·31	2·88	1·83	20·36
2	2·02	0·61	2·67	2·50	3·68	1·32	5·01	4·28	2·45	1·15	1·43	0·77	27·89
3	1·55	3·09	1·30	0·56	2·30	1·71	2·28	2·00	0·59	0·63	1·52	0·92	18·45
4	1·48	0·64	1·92	3·16	2·25	2·39	2·26	2·34	1·44	1·95	2·64	1·86	24·33
5	1·49	0·94	0·23	0·26	0·70	1·48	1·29	2·14	4·26	2·34	1·74	1·76	18·63
6	3·01	0·62	1·28	0·86	2·44	1·28	0·52	1·75	3·15	4·04	2·24	2·21	23·40
7	0·30	1·81	2·54	0·80	1·48	1·04	5·22	1·08	1·38	2·38	1·44	2·60	22·07
8	0·67	2·17	0·77	0·42	0·40	2·34	0·78	3·37	2·01	0·17	0·50	0·31	13·91
9	2·65	2·05	1·82	1·33	2·62	5·02	4·45	1·28	3·11	3·75	1·54	1·75	31·37
1790	1·38	0·19	0·40	1·88	2·67	1·16	2·20	2·19	0·65	0·61	3·48	2·51	19·32
1	3·24	1·55	0·41	1·51	0·93	0·60	2·82	1·45	0·71	3·22	4·54	2·20	23·18
2	3·01	0·53	1·79	2·99	1·92	2·75	2·94	3·28	3·73	3·57	0·87	1·39	29·77
3	2·32	1·23	1·66	1·95	1·74	0·62	2·41	1·63	4·42	0·93	1·673	1·90	22·52
4	0·50	1·00	1·29	2·08	2·11	0·61	2·69	1·87	2·70	3·15	4·81	2·07	24·88
5	0·51	2·36	2·10	1·80	0·06	5·53	2·09	2·23	0·24	4·28	1·95	1·97	25·12
6	3·02	1·45	0·47	0·23	2·37	0·85	3·47	1·75	1·20	2·16	0·72	2·38	20·11
7	1·50	0·32	1·81	1·50	1·32	4·26	2·57	2·81	5·75	0·96	2·16	3·32	28·24
8	2·16	0·00	0·46	1·71	1·82	1·15	4·78	2·03	2·36	4·15	4·4	1·16	26·24
9	1·82	2·75	1·07	2·88	2·16	0·55	3·54	3·49	6·33	3·49	2·26	0·73	31·07
1800	2·80	0·53	1·66	2·83	1·98	0·66	0·05	1·27	3·06	2·68	6·05	2·43	26·00
1	1·42	0·43	1·33	0·21	2·92	1·62	2·27	2·14	1·75	1·92	2·95	2·05	21·01
2	0·36	2·05	0·27	0·27	1·77	1·80	3·38	0·28	0·26	1·62	1·69	2·34	16·09
3	2·07	1·62	0·24	0·69	0·80	2·84	1·76	0·76	0·90	0·28	4·44	4·35	20·75
4	2·92	0·67	3·20	2·09	2·18	0·60	3·56	2·10	0·33	3·02	2·69	0·85	24·21
5	2·11	1·04	0·63	1·68	1·55	1·80	1·49	2·09	1·73	1·83	0·88	1·99	18·82
6	3·39	1·40	1·77	0·91	1·03	0·73	3·61	1·86	1·54	1·02	2·85	3·57	23·68
7	1·24	1·23	0·47	0·38	3·37	1·25	1·79	1·59	2·47	1·89	4·05	1·36	21·09
8	0·99	0·94	0·35	2·87	2·01	1·31	3·07	2·12	2·53	3·51	2·31	1·31	23·32
9	4·33	2·61	1·26	3·51	1·31	1·48	3·20	3·22	3·23	0·17	1·49	2·77	28·58
1810	0·65	1·52	2·29	2·25	1·83	1·11	3·49	2·57	1·19	2·13	5·41	3·42	27·86
11	1·55	2·13	1·41	1·77	3·83	2·09	3·32	1·97	1·86	3·41	2·51	1·55	27·40
12	1·61	3·51	2·85	1·67	2·83	3·07	2·03	1·42	0·95	4·37	2·35	0·45	27·11
13	1·16	3·61	0·75	1·32	2·14	1·13	1·91	0·88	1·51	4·60	1·10	0·61	20.72
14	2·38	0·31	1·27	2·50	1·04	2·32	2·67	1·27	1·59	2·33	1·50	3·32	22·50

present paper, that Hornsby's record from 1775 to 1805 refers to a gauge in the same site and exposure as that used from 1815 to 1850, provides a valuable addition to the records known to span this gap and justifies the time spent on the patching of this fragmentary record. Finally, it should be noted that the figures in Table VI are quite independent of others being made at the same period, for example, at Lyndon, Manchester and Liverpool, and almost independent of the homogeneous series for Kew published by Wales-Smith (1971). Hence, resemblances between the series, which may be brought to light by any of the various forms of spatial analysis, must be meteorological in origin, and not due to the derivation of data from a common source.

14. ACKNOWLEDGEMENTS

Acknowledgement is due to Professor G. Manley, to Mr C. G. Smith of Keble College, Oxford and to Mr B. G. Wales-Smith of the Meteorological Office, for assistance with data and constructive comment; to the Librarian at the School of

Geography, Oxford, for access to the Hornsby manuscripts; and to the staff of the Meteorological Office for access to and copies of relevant records in the official archives.

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AN UNUSUAL LIGHTNING INCIDENT IN SINGAPORE

By J. E. PAKIAM and A. RAJARATNAM
(University of Singapore)

SUMMARY

An account is given of a lightning strike which fatally injured a soldier and badly damaged his equipment. An estimate is made of the energy needed to produce the damage and it is shown that this is well within the limit of that likely to have been available.

Introduction

It is unusual for lightning to strike a person directly and even more unusual for it to leave some evidence of the physical nature of the lightning channel. In November 1973, during a heavy thunderstorm, a group of Armed Forces personnel was struck by lightning, one man suffering the full impact of the strike, with subsequent death. Evidence of the lightning strike was gathered from eye-witness reports, the medical report and condition of clothing, weapon and helmet. From measurements made on the helmet it was possible to estimate (i) the nature and size of the lightning flash, (ii) the temperature structure of the lightning channel, (iii) the action integral $\int I^2 \, dt$, and (iv) the energy required to create the hole in the helmet.

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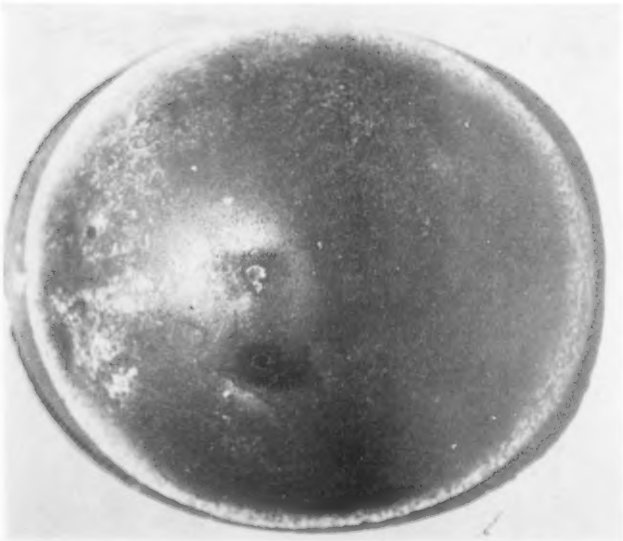

PLATE I—HOLE CAUSED BY LIGHTNING STRIKE TO HELMET

(See page 373.)

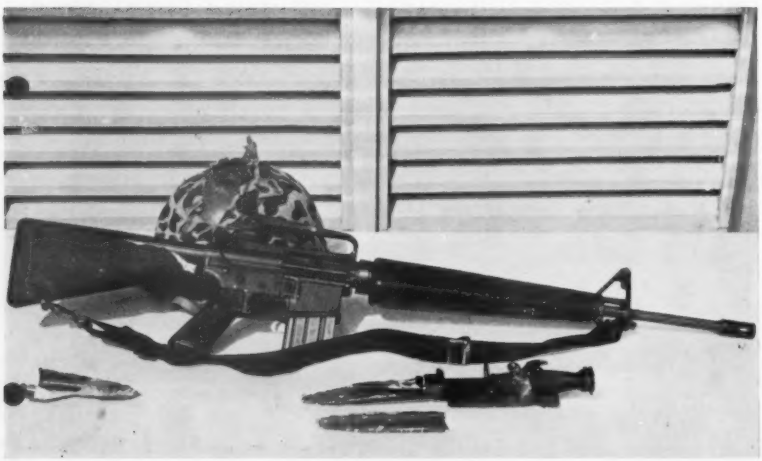

PLATE II—DAMAGE BY LIGHTNING STRIKE TO HELMET, RIFLE AND BAYONET

Note hole in helmet (cloth covering partly torn) and damage to rifle butt and bayonet scabbard. (See page 373.)

To face page 373

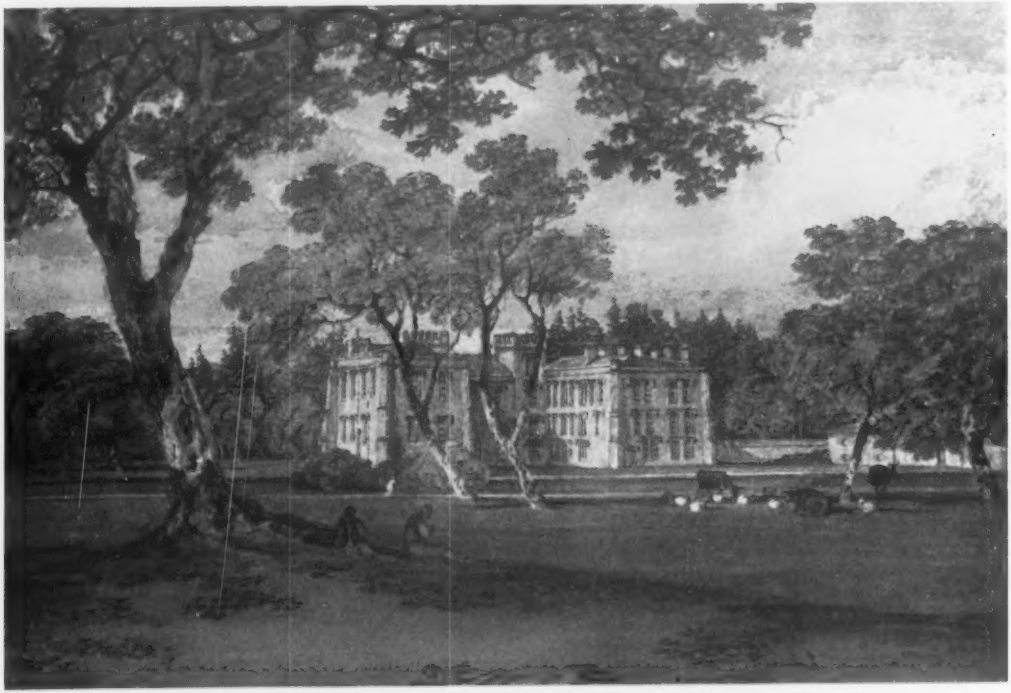

PLATE III—TOWNELEY HALL, NEAR BURNLEY, LANCASHIRE

(See page 378.)

The incident

At 1530 hours local time on 19 November 1973, while on training on the top of a small hill about 100 m above sea level, the group was struck by lightning during a thunderstorm. One man was struck directly and died subsequently while 24 others were injured, none seriously. From written eye-witness reports, the circumstances related to the incident are as follows:

(1) Rain began falling on the hill around 1500 hours Local Standard Time and lightning was observed to strike a tree close to the group position.

(2) As the group began to descend the hill to seek shelter, a flash struck a soldier, and 24 other men close by were thrown to the ground, probably by ground-induced currents. With the exception of the man directly struck, all the men recovered quickly and ran for help.

(3) When medical help arrived in a few minutes, the injured man was unconscious. Mouth-to-mouth resuscitation was applied and the man was moved to hospital but was pronounced dead on arrival.

Bodily injuries

The dead soldier had his uniform torn and tattered all the way down from the chest to the knees. Part of the hair was burnt and one side of the body (face and chest) was blue-black in colour and the helmet and weapon were found to be damaged.

The other injured men all reported 'feeling an electric current passing through' or 'feeling numb', sensations which are typical of 'step voltages' (Golde and Lee, 1976). On being thrown to the ground some lost consciousness for a few seconds but all recovered quickly. No serious injuries resulted to the 24 men, who were medically examined and discharged.

Damage to the weapon and helmet

On examination of these objects it was immediately obvious that the dead soldier had sustained a direct lightning strike. A small hole was discovered on the top of the helmet and several melt points in the steel were present (Plate I). The plastic inner liner under the steel helmet was undamaged. One side of the helmet (near the buckle for the strap) was blackened and the buckle itself appeared to have been blown off. The rifle had several melt points on all its sharp edges (end of barrel, trigger etc.) and the butt had been damaged. The bayonet had part of its scabbard blown off (Plate II). The boots showed no sign of damage.

From the damage, it appears that the lightning currents must have flowed from the helmet down one side of the face and body, to the weapon (which was probably slung over the shoulder), and down the butt, before jumping to the ground. Such an explanation seems reasonable in view of other similar incidents reported in the literature (Golde and Lee, 1976).

The helmet

The helmet was examined in greater detail, as it provided some evidence for the size and temperature of the lightning flash. Seven different burn areas were noted on the top of the helmet, one hole also being present. Three other small burn areas were noted on the side of the helmet and the rear.

Each burn area was found to consist of a number of patches of different colours. Generally there existed a central blackened area, surrounded by a silvery patch, then by a reddish patch and finally by a slightly black-grey area, darker than the surrounding green-grey of painted steel.

The hole and surrounding burn patches were all approximately circular and from the planimetered areas the diameters could be computed for equivalent circular areas.

In the interior of the helmet a large irregularly shaped dark area (about 16 cm^2) near the strap was noted.

Diameter of different burn patches. Measurements of the various hole and burn areas were taken and the equivalent diameter for circular areas calculated. The results for the 10 different burn areas are presented in Table I.

TABLE I—DIAMETER OF BURN PATCHES ON HELMET

Area No.	Diameter of hole	Diameter of darkened area	Diameter of silvery area	Diameter of reddish area	Diameter of black-grey area
	mm	*mm*	*mm*	*mm*	*mm*
1	7·12 (outside of helmet) 4·50 (inside of helmet)	—	8·74	10·3	≈14·0
2	—	4·22	5·52	6·0	D*
3	—	—	1·78	D	D
4	—	Extremely small	2·52	D	D
5	—	Extremely small	2·98	D	D
6	—	—	3·90	D	D
7	—	—	2·00	D	D
8	—	—	1·38	D	D
9	—	Extremely small	4·22	D	D
10	—	—	3·56	D	D

* D = Difficult to estimate, because areas very diffuse.

LIGHTNING DIAMETER MEASUREMENTS IN THE LITERATURE

Few measurements of the diameter of the lightning channel have been made.

Photographic measurements showed the diameter to vary from between 3 cm and 16 cm (Schonland, 1950 and Evans and Walker, 1963). Orville *et alii* (1974) more recently reported photographic evidence of return strokes with diameter in the range 6 to 7 cm. Direct lightning strikes (return strokes) on fibreglass screens were made by Uman (1964) and these have shown (a) nearly circular holes, and (b) equal numbers of holes with diameters in the ranges 2–3·5 cm and 2–5 mm. Uman also discussed the problem of the definition of the term 'diameter' since clearly there is no definite boundary between the stroke and the air surrounding it. Measurements of strikes on metal electrodes (Hill, 1963) showed that the diameter was of the order of millimetres, and measurements of scars on trees struck by lightning indicated values in two ranges 0·5–3 mm and 1–8 cm (Taylor, 1965). Uman (1969) has cautioned on the deduction of channel diameters from electrode measurements. In a theoretical computation of the diameter of the return stroke Oetzel (1968) showed that the diameters of first

return strokes lie in the range 1–4 cm, with subsequent return strokes in the range 0·2–0·5 cm. Other measurements of the diameters of the lightning return stroke have been reviewed by Orville *et alii* (1974).

Measurements made on diameter and temperature

The measurements reported here are in the class of electrode measurements. Nevertheless, with the reservations expressed by Uman, it is possible to obtain a rough idea of the diameter of the lightning flash which struck the soldier.

A wide range of values of the core temperature of a flash have been postulated (Uman, 1969) and a value of 25 000°C would be reasonable. The hole would correspond to an area having experienced a temperature of >3000°C (the boiling point of steel). Assuming that the silvery patches were formed by melting steel, such an area could be regarded as having had a temperature of >1500°C. Red patches would correspond to Fe_3O_4 formed at temperatures up to ≈570°C. The grey-black patches (Fe_2O_3) would be formed when temperatures of >220°C occurred. With these assumptions, it was possible to plot a graph of radial temperature distributions within the lightning flash (Figure 1).

From the graph, it is obvious that the temperature falls off very rapidly with distance from the core, the central core of high temperature being of very small diameter. If a temperature of 2000 K is assumed to be a limit for the diameter of the lightning channel, then such a temperature corresponds to a lightning channel diameter of about 1 cm (Uman, 1969). This compares favourably with the experimental measurement of this study (≈0·8 cm for a temperature of 2000 K, Figure 1).

Calculation of action integral $\int I^2 dt$

Golde (1973) has noted that the action integral $\int I^2 dt$ is generally used to evaluate holes formed in thick metal by lightning.

As a first step in the calculation of $\int I^2 dt$, the electrical charge that passed through the hole was estimated. The diameter of the hole on the outside of the helmet was 7·12 mm with an area of 40 mm²; the composition of the helmet was an unknown steel alloy of thickness 1·3 mm. Golde (1973, page 53) has presented the results of Hagenguth regarding the relation between charge and size of hole burnt in metal sheets of different composition and thickness. From Hagenguth's results it was estimated that the charge passing through the hole was about 75 coulombs. This is a little higher than the average charge transferred per flash (31 C) found by Wang (1963) for Singapore.

As the second step, the maximum current and the duration of the lightning flash were estimated. Since the charge transfer of 75 C was more than twice the average for Singapore, the lightning flash could be considered to have had, say, a 10 per cent frequency of occurrence. No statistics for peak current have been obtained at Singapore but, from Golde (1973, page 17), a peak current of about 75 kA was estimated. A mean current of about half this value can be assumed. The time of current flow would be about 10^{-3} s, a plausible value.

Using these values of mean current and time, the action integral $\int I^2 dt$ works out to be about $1{\cdot}4 \times 10^6$ A^2s, which is within the range for negative discharges (Golde, 1973, page 19).

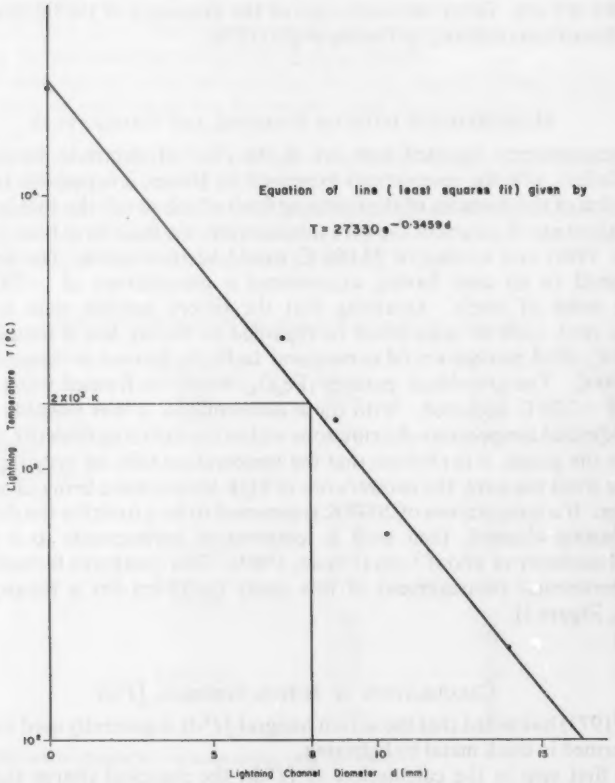
Equation of line (least squares fit) given by
T = 27330 e^-0·3459d
2 x 10³ K
Lightning Temperature T (°C)
Lightning Channel Diameter d (mm)

FIGURE I—RADIAL TEMPERATURE DISTRIBUTION WITHIN LIGHTNING FLASH

CALCULATION OF ENERGY REQUIRED TO FORM HOLE IN HELMET

The average surface area of the hole was 0·28 cm², so that the approximate volume of the steel vaporized was 0·0364 cm³. Assuming the latent heat of vaporization to be 351 kJ mol^{-1} the total energy required to form the hole will be rather more than $351 \times (0{\cdot}29/56)$ kJ ≈ 2 kJ.

The probable maximum electrical energy associated with the lightning flash would be $IVt = 7{\cdot}5 \times 10^8$ J, assuming a value of 10^7 volts for V. The minimum value would probably have been about 10^8 J. This energy would have been dissipated over the whole path of the lightning stroke from cloud to ground which was probably several kilometres long. The height of the soldier and his bayonet would have been about 2 m so that the energy available for creating the hole, killing the man and damaging his equipment would be about 10^{-4} to 10^{-3} of 10^8 J, i.e. 10^4 J to 10^5 J, certainly well in excess of the quantity estimated above as necessary to create the hole.

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PLATE IV—INTERNATIONAL COMPARISON OF DOBSON OZONE SPECTROPHOTOMETERS, BOULDER, COLORADO, AUGUST 1977

(See page 385.)

PLATE V—INTERNATIONAL COMPARISON OF TOTAL OZONE MEASURING INSTRUMENTS, BELSK, POLAND, JULY 1974

Mr J. H. Convery is standing behind the UK instrument at the right of the photograph, and Miss A. Mani, the WMO Rapporteur on Measurements of Atmospheric Ozone, is seated in the foreground. (See page 385.)

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PLATE VI—THE METEOROLOGICAL OFFICE EXHIBIT AT THE SILVER JUBILEE EXHIBITION AT THE ROYAL SOCIETY, LONDON

The exhibit is being explained by the Director-General of the Meteorological Office and Treasurer of the Royal Society, Dr B. J. Mason, C.B., F.R.S.

PLATE VII—ANOTHER VIEW OF THE METEOROLOGICAL OFFICE EXHIBIT

(See page 380.)

Conclusions

From measurements made of a direct lightning strike on to a metallic helmet, a lightning diameter of ≈0·8 cm was deduced. In view of the many assumptions made in the study, the deduced value compares favourably with other measurements reported in the literature.

Rough estimates indicate that a charge transfer of 75 C over a period of about 1×10^{-3} s was responsible for the formation of the hole. With a peak current flow of 75 kA, the action integral $\int I^2 dt$ was calculated to be about $1{\cdot}4 \times 10^6$ A^2s, which is within the range for negative discharges.

Another calculation showed that the energy required for the formation of the hole was about 2 kJ. Energy of about 10^4 to 10^5 J was involved in damaging the human body, weapon and bayonet.

Acknowledgements

The authors are grateful to the Ministry of Defence of the Republic of Singapore for permission to examine reports, weapon and helmet. Technicians Mr Yee Cheong Inn and Mr V. Thomas are thanked for measurements on the helmet and photography respectively. The Figure was drafted by Mr Tow Fui. We are indebted to Dr R. H. Golde for his helpful criticisms and invaluable suggestions in improving the manuscript.

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RAINFALL RECORDING IN THE BRITISH ISLES 1677–1977

By R. P. W. LEWIS

The year 1977 must not be allowed to pass into history before mention has been made in the *Meteorological Magazine* of the tercentenary of the start of systematic rainfall recording in the British Isles.

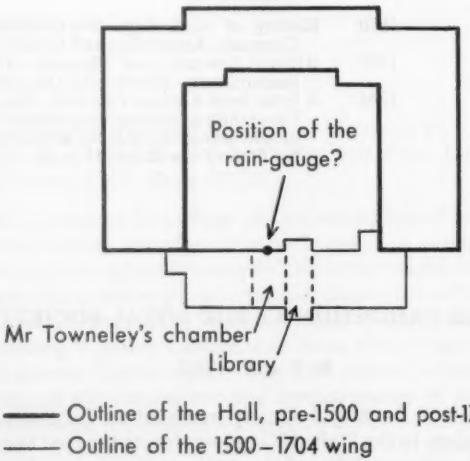
Rain-gauges of a sort are known to have been used in India in the 4th century B.C., in Palestine in the 1st century A.D., in China by A.D. 1247 and in Korea by A.D. 1441. They were, however, apparently unknown in Europe until the 17th century when Benedetto Castelli made some measurements in Italy in 1639.

In 1662 Sir Christopher Wren demonstrated an elaborate recording rain-gauge of his own design and construction to the Royal Society, but it does not seem to have been used to make systematic regular measurements. In January 1677, however, Richard Towneley* of Towneley Hall, near Burnley, Lancashire (see Plate III) began to make careful observations of the rainfall at his home and kept and published records of montly totals from that time until April 1704. Towneley was doubtless familiar with Wren's work but the details of his own gauge were almost certainly original; it would seem to have collected the rain falling at the level of the roof of Towneley Hall (Biswas, 1970). In a report published in the *Philosophical Transactions of the Royal Society* in 1694 he wrote:

'I fixed a Round Tunnel of 12 inches Diameter to a Leaden Pipe, which would admit of no water, but what came through the Tunnel, by reason of a part soder'd to the Tunnel itself, which went over the Pipe, and served also to fix it to it, as well as keep out any wett that in stormy weather might beat against the under part of the Tunnel, which was so placed that there was no building near it that would give occasion to suspect that it did not receive its due proportion of Rain that fell through the Pipe some nine Yards perpendicularly, and then was bent into a window near my chamber, under which convenient Vessels were placed to receive what fell into the Tunnel; which I measured by a Cylindrical Glass, at a certain mark containing just a Pound or 12 Ounces *Troy*, and had marks for smaller parts also. By the help of this Cylindrical Glass I thus kept my account of what Rain fell, and generally twice or thrice a Day; when I took several other Observations, both of the *Thermometer*, *Barometer*, Winds, &c.'

Plate III shows a black-and-white photograph of a colour reproduction of a painting of the north-east aspect of Towneley Hall executed by J. M. W. Turner in 1799. In about 1700 a fourth wing which had completely enclosed the inner courtyard was pulled down. This wing contained a room known as 'Mr Towneley's chamber' and, presumably, the 'tunnel' was fixed to its roof. Professor

* The spelling of Richard Towneley's surname varied from one contemporary source to another. However. S. P. E. C. W. Towneley, Esq. of Dyneley, Burnley, Lancs. has informed us that the spelling 'Towneley' was used by his ancestor on his book-plate, and we have in consequence adopted it for this article.


Position of the rain-gauge?
Mr Towneley's chamber
Library
Outline of the Hall, pre-1500 and post-1704
Outline of the 1500–1704 wing

PLAN VIEW OF TOWNELEY HALL FROM A SKETCH PLAN KEPT AT BURNLEY

Gordon Manley has visited the Hall and has estimated that the tunnel was probably above the level of the battlements which now adorn the remaining wings. (Acknowledgement is made to the Towneley Hall Society for permission to photograph their colour reproduction of a Turner painting.)

Although Towneley obviously knew the importance of eliminating both leaks and water that might run down the outside of his tunnel and of making sure that the mouth of the tunnel was unobstructed, he was unaware of the serious effects of 'over-exposure' and of the action of wind eddies in reducing the catch of gauges that were placed high up on buildings or poles; these effects were not indeed properly elucidated until the mid-nineteenth century and most early gauges were placed on roofs or high walls to avoid vandalism or mischievous interference. Ever since Towneley's day, systematic rainfall observations have continued to be made somewhere in the British Isles, the longest series being that at the Radcliffe Observatory, Oxford, which is continuous from 1815 to the present day and extends in a broken form back to 1795; the Meteorological Office now collects and analyses records from more than 7000 gauges in Great Britain and Northern Ireland, and information of immense value is provided for agriculturists, hydrologists, civil engineers, insurance companies, and many others. It is doubtful whether so shrewd a scientist and observer as Towneley would have been surprised at the great developments of modern hydrometeorology, but he would certainly have been gratified to know that so much has developed fom the small beginnings at Towneley Hall.

A fuller account of the rainfall measurements of Towneley Hall is given by Folland and Wales-Smith (1977).

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SILVER JUBILEE EXHIBITION AT THE ROYAL SOCIETY, LONDON

By F. R. HAYES

In May and June 1977 the Royal Society mounted an Exhibition illustrating scientific developments in the United Kingdom during the past twenty-five years in celebration of the Silver Jubilee of Her Majesty the Queen. In common with other bodies the Meteorological Office was invited to provide an exhibit. For most of the period of the Exhibition there were 12 exhibits but additional ones, making a total of 22, were provided for a conversazione in May and a Ladies' Evening in June at which 1200 guests were present.

Exhibits covered many aspects of scientific achievement. Of interest were live displays of a pulsar and a quasar tracked by the 250 ft telescope and a short-baseline interferometer at Jodrell Bank, and a demonstration of chemical changes, of a few picoseconds' duration, detected by mode-locked lasers.

Several exhibits concentrated on the development of instruments arising from scientific discoveries. The smallest radar ever made was on show, incorporating the discovery of indium phosphide as a microwave source, and liquid crystals as low-power visual display. Powered by small solar cells, it stands about 25 cm high! Fibre optic communication, precision aircraft guidance by microwaves and the BBC 'Ceefax' system were among other developments on display.

Molecular biology was not to be left out, and a range of analytical methods and discoveries in this field was shown, including a rapid and simple method of determining nucleotide sequence in DNA, and the structure and assembly mechanism of Tobacco Mosaic Virus. An exhibit from the field of biology showed the discovery of drugs used in the treatment of high blood pressure.

The Meteorological Office exhibit covered three aspects of modern weather forecasting: satellites, radar, and numerical forecast models. The centrepiece was a video film showing animated output from the 10-level operational forecast computer model; it demonstrated how satellite and radar techniques are related to the production of more reliable forecasts. Experimental numerical models shown were the fine-mesh boundary-layer model for short-period forecasting and the general-circulation model for long-period forecasting. Modern instruments, and a mock-up of automated data retrieval from the computer data banks completed the exhibit. The preparation of the artwork and the construction of the stand were carried out by Met O 18d (Cartographic Section). (See Plates VI–VII.)

REVIEWS

Introduction to meteorology (*second edition*), by Franklyn W. Cole. 225 mm × 160 mm, pp. xx + 495, *illus.*, John Wiley and Sons Ltd, Baffins Lane, Chichester, Sussex, 1975. Price: £5.25.

This textbook is designed for college and university liberal arts students, who have little prior knowledge of mathematics and physics. Consequently space has to be devoted to explaining basic principles and to the reader with any acquaintance with the physical sciences gained at school these parts will make rather dull reading. In spite of this limitation, Professor Cole, who is Professor of Meteorology and Engineering, Foothill College, Los Altos Hills, California, attempts a wide survey of meteorological topics. The first section, which deals with the general properties of the atmosphere and measurements of pressure, temperature, humidity and wind is followed logically by a section on physical processes in the atmosphere. The third and fourth sections deal with Atmospheric Motion and Circulation and with Weather Disturbance and Change. The last part deals with the application of meteorology to forecasting, to climatology and to the environment.

In the review of the first edition (*Meteorological Magazine*, Volume 100, 1971, pp. 125–126) the main criticism levelled at this book was its parochial nature, as it rarely looked beyond the boundaries of the United States. This criticism must still stand but the addition of many useful satellite pictures and the extra chapter on 'Climate and Climate Controls' have subtly widened the scope of the book. Unhappily, there is still a lack of uniformity in the system of units employed. Temperature in degrees Celsius and Fahrenheit, pressure in millibars and inches and wind speed in knots and miles per hour all find a place. This confusion must be a serious drawback in using this book as a text associated with a formal course.

On the other hand the book has many good qualities. Even though constrained to use an essentially descriptive approach the author imparts a clear understanding of the principles of atmospheric physics in the first two sections. The lack of mathematics is more keenly felt in dealing with dynamical meteorology but some well-chosen diagrams help to give a good approximation of three-dimensional motion in the atmosphere. In the chapter on forecasting one must commend the juxtaposition of satellite photographs of cloud cover and the corresponding synoptic charts. It is a great pity that the idea is spoilt by the poor quality of printing of the charts. The glossary of physical and meteorological terms provided at the end of the main text is also a valuable feature.

In summary, the changes made in the second edition have undoubtedly increased the value of the book, but more needed to be done. For example, the type of reader for whom the book is designed would acquire no idea of the all-pervading impact of electronic computers in meteorological communication, data processing and numerical forecasting. Consequently he would fail to appreciate the ability of his National Meteorological Service to render him assistance in his chosen profession. Although the book makes interesting reading, it cannot be recommended as a primary text.

P. D. BORRETT

Annual Report of the Central Water Planning Unit for the year ending 31st March 1976. 295 mm × 210 mm, pp. 66, *illus.*, Central Water Planning Unit, Reading Bridge House, Reading, Berks. RG1 8PS, 1976.

This report on the second year of the Unit's work will be of interest to anyone with a serious concern for the water resource planning of England and Wales. The Unit was formed in the reorganization of the water industry (following the Water Act of 1973) to provide a 'service of planning expertise to the Government, the National Water Council and the Water Authorities'.

The text contains 32 illustrations including photographs, maps and clearly designed diagrams. It has obviously been conscientiously proof-read since a sheet of corrigenda appears inside the front cover.

The Unit is closely associated with the Meteorological Office at all levels. The Director is the Director-General's Hydrological Advisor for the World Meteorological Organization and there has been a fruitful relationship, especially with the branches concerned with Synoptic Climatology and with Agriculture and Hydrometeorology.

The second section of the report deals with 13 projects which include the feasibility of constructing reservoirs in the Wash Estuary, synthesizing river flow records from the longer and more numerous meteorological records and the much-discussed topic of water transfer between major rivers. There are four technical appendices presenting additional information on Severn to Thames water transfer simulation studies, a geology index for river flow studies, nitrates in water supplies, and river-regulation losses.

Signs of co-operative efforts between the Unit and the Office are to be found in several parts of the report; examples include the recognition that current meteorological methods underestimate the winter evaporation (page 20), operational losses in river-regulation systems (page 24), the very important Dee Weather Radar project (page 26) and the studies of the variability of long-duration rainfall (pages 30–32).

Many meteorological readers will find the map on page 21 of special interest. Reproduced from the 1865 *Report of the British Association for the Advancement of Science*, it shows the rainfall measuring stations operating in that year. Some will be surprised to see how well most parts of Great Britain were represented, whilst others, aware that we now count the network in thousands, may be equally surprised that almost every station could have its own dot on such a small-scale map as recently as 112 years ago.

The report is to the point and highly readable.

B. G. WALES-SMITH

Ministry of Agriculture, Fisheries and Food Technical Bulletin 35, The Agricultural Climate of England and Wales (Areal Averages 1941–70), by L. P. Smith. 250 mm × 160 mm, pp. vi + 147, *illus.*, Her Majesty's Stationery Office, Atlantic House, Holborn Viaduct, London EC1P 1BN, 1976. Price: £2·40.

Over the years the Agricultural Meteorology Section of the Meteorological Office in general, and L. P. Smith in particular, have made immensely valuable contributions to our understanding of the farming climate and weather of

Britain. They have drawn information from a wide range of sources, including the national network of crop-weather stations, and have presented it in the form of intelligible summaries that have been widely used by research workers, advisory officers and the farming community. Much useful information and advice has also been enshrined in a long series of memoranda that have deserved a wider circulation than they were usually given.

This Bulletin is the latest, and best, of the Meteorological Office's agricultural publications, and it is a fitting monument to the years of devoted work by Smith and his colleagues. The Bulletin carefully defines the main meteorological variables that are considered to affect farm decision-making and animal and crop husbandry. It then gives a short account of each of these attributes in the course of some 30 pages, and finally provides an astonishing amount of detailed information about the so-called 'areal' averages for each of the 56 homogeneous weather regions into which England, Wales and the near-by islands have been divided.

No comparable compendium has been published before for Britain (or elsewhere?), and the Bulletin will be invaluable in a variety of ways for a long time to come. The information could be specially useful in such managerial exercises as choosing the best site for a particular crop, or in selecting crops which would have a high potential on any particular site. Selecting crops for sites, and vice versa, has been the staple of decision-making since farming began, but it has perforce been based on hard-earned experience and empirical wisdom until now, in the absence of firm information about local climates and weather. This Bulletin goes far towards providing a new and sounder base for the management decisions involved.

The choice of the best crops for a site is particularly relevant to farm management, since the individual farmer and grower is not usually concerned with areal averages but with what he should do, and the likely consequences of his actions, on a particular farm or field. It is easier to characterize small areas if they form part of the flat plane surface of infinite extent so beloved of the theoretical physicist, and the Bulletin has understandably sought to simplify its daunting task by reducing all data to averages for level ground. However, much of Britain is rolling, hilly or mountainous, and it should not be beyond the wit of man to find a usable method of extrapolating from such data to allow for the effects of aspect, altitude, slope and distance from the sea—indeed, a start has already been made on some of these effects (e.g. on pages 6 and 18). The Bulletin observes that 'It is difficult to quantify the effect of slope and aspect, as no observational details are available . . .', but steps should perhaps be taken to start collecting such data when the Meteorological Office seeks new topics on which to work in the agricultural field.

There are other limitations to what meteorologists can do for agriculture, as the author is only too well aware. For instance, it is stated that 'Maximum and minimum air temperatures were not treated separately, as they are too much dependent on local site characteristics' (page 2), yet it is precisely those extremes that may make or mar a farming operation. The Bulletin would gain in value if ways could be found of providing guidance on the probable occurrence of such extremes.

It has recently been announced that the agrometeorological cover of the MAFF Agricultural Development and Advisory Service has been expanded. This Bulletin should provide the officers in that service with a powerful new tool.

They, and many others, have cause to be grateful to L. P. Smith and his colleagues for this Bulletin, and for their other contributions to agrometeorology.

J. P. HUDSON

Earth, the living planet, by Michael Bradshaw. 275 mm × 215 mm, pp. 302, *illus.*, Hodder and Stoughton Educational, Mill Road, Dunton Green, Sevenoaks, Kent, 1977. Price: £4·95 (paperback).

This book is written as a reader for sixth form and college courses in physical geography and environmental science. It has several aims: to establish basic ideas and themes, thereby leading the reader to field observations and to regular perusal and assessment of the popular scientific press; to attempt an explanation of the environmental 'coincidences' which have led to the life-forms of this planet; and, by placing the debate on conservation and pollution on a more informed footing, to put the reader in a position to be more capable of assessing the question 'will the living planet die?'.

The first quarter (seven chapters) of the book is devoted to a non-mathematical treatment of basic meteorology, the atmospheric heat-engine, air–sea interactions, weather systems, cloud microphysics, weather modification, and forecasting (at about the level of *Elementary Meteorology* (HMSO)). The next eight chapters look at world climates, past and present, and implications for the future.

'Ecology of life on earth' is the subject of the latter half of the book. Starting with an introduction to the various life-forms we study the constraints on life which, in addition to energy and nutrient chains, affect the biosphere—climate, soil, the interrelationships of animals and plants, and finally the influence of man. The final chapters discuss the distribution of living creatures on the earth's surface and their adaptation to optimum and extreme conditions and conclude with a study of the teeming oceanic life and possibilities of enhancing oceanic production.

The book has a clear format, copious well-explained diagrams, graphs, tables and monochrome photographs, as well as over 80 colour pictures in a block near the centre of the book, and covers subjects ranging from soil classification and woodland tree types to pictures of cloud formations, from earth and from space, illustrating the scales and forms of atmospheric motions.

Many of the figures and pictures are accompanied by questions requiring careful study and interpretation of the text and figures. Perhaps more emphasis could have been placed on suggestions for simple experiments and investigations in which the reader could demonstrate or explore for himself some aspects of the text (as, for example, in L. P. Smith's *Weather Studies*).

A good bibliography is presented for readers wanting a broader or deeper treatment of various topics; it has several sections covering source books and more advanced texts (published since 1970).

Those of us who are involved in what are essentially interdisciplinary studies such as agricultural meteorology have some idea of the value of meteorological studies to a world growing increasingly short of food; Michael Bradshaw here introduces the student and general reader to interdisciplinary studies and emphasizes the necessity of this approach in order to investigate the delicate equilibrium in which nature is maintained and in which man is increasingly able to interfere.

It is to be hoped, though, that students will appreciate that many aspects covered in the chapters can be, and have been, placed on a strong mathematical foundation and that they will not regard 'environmental studies' as purely descriptive, an easier option for examination work.

Perhaps the author becomes too enthusiastic in his attempts to explain the 'incredible' coincidences which have combined to produced life on earth. A question for the student might be to assess the probability that there are 10^9 Michael Bradshaws distributed round the universe and all writing books (with their various combinations of extremities) about their 'living planet' and enthusing at the amazing coincidences that have led to life as they know it!

For the student and general reader the volume certainly presents a useful introduction to the physical, chemical and biological forces and processes which interact to produce and maintain life. The author summarizes the possible implications of man's misuse of some of these interactions in a balanced and unsensational manner and should put the reader in a better position critically to assess future development.

J. R. STARR

Meteorological Magazine: price increase

As from January 1978 the price of an issue of the *Meteorological Magazine* will be £1 and the annual subscription will be £13·14 including postage.

NOTES AND NEWS

International comparison of Dobson ozone spectrophotometers

Mr J. H. Convery of the High Atmosphere Branch of the Meteorological Office visited the NOAA Environmental Research Laboratory, Boulder, Colorado, USA in August 1977 and took part in an international comparison in the course of which Dobson spectrophotometers from Canada, Australia, India, Japan, the German Democratic Republic, Norway, Egypt and the United Kingdom were operated alongside the USA 'standard' instrument. The comparison was sponsored by the World Meteorological Organization, and the UK instrument performed satisfactorily throughout the lengthy sets of simultaneous observations (see Plate IV). Plate V depicts an earlier international comparison which took place in Belsk, Poland in 1974.

Association of British Climatologists

The Association now forms the Specialist Group in Climatology of the Royal Meteorological Society. The Steering Committee comprises:

B. W. Atkinson	*Chairman*
L. F. Musk	*Secretary*
Joan Kenworthy	*Treasurer*
C. Finch	
F. H. W. Green	
K. Smith	
P. A. Smithson	

Future meetings include one provisionally entitled 'Climatological research in the Meteorological Office' to be held on 6 January 1978. Enquiries about this meeting and membership of the group should be sent to L. F. Musk, School of Geography, University of Manchester, Manchester.

Retirement of Mr W. D. S. McCaffery

Mr W. D. S. McCaffery, Assistant Director, Personnel Management, retired on 18 November 1977 after a career of more than 38 years in the Meteorological Office. His concern for the efficiency of the Office coupled with a warm understanding of the interests of the staff made him ideally suited to personnel management, a field in which he specialized for the last nine years of his service. Under his guidance the merger of the scientific classes was successfully accomplished and the Office was able to lead the way with many post-Fulton reforms in career development.

Sinclair McCaffery graduated with first-class Honours in Physics at the University of Durham and joined the Office a few weeks before the outbreak of the second world war. With little preparation, he was sent overseas to Malta where he spent four years in operational forecasting under the most difficult conditions, having on one occasion to evacuate a severely damaged building during the height of a blitz and maintain a service through the succeeding night. He was commissioned into the RAFVR in 1943 and served as a Flight Lieutenant at HQ 18 Group until just after the end of the war. In the reconstruction period, he rejoined the Civil Service as a Senior Scientific Officer spending three years in Negombo, and two years at Pitreavie. In this period he went noticeably out of his way to assist his staff with their studies and his posting to the Training School in 1952 was therefore particularly appropriate. On promotion to Principal Scientific Officer in 1955 he joined the senior forecasting roster in Met O 2 and proved to have the ideal temperament for this exacting task which he performed with distinction for no less than eight years. In 1963 he moved to the Techniques and Training Branch (Met O 8) to apply this wide synoptic background and experience to the task of examining forecasting techniques at outstations and to the solving of local forecasting problems. After a brief spell back in the training field and another in charge of London Weather Centre he joined Met O 10 and soon made his mark as an able administrator. He was promoted to Senior Principal Scientific Officer in 1972.

It has been a pleasure to work closely with Mr McCaffery for the past two years. His quiet, unassuming manner, his impartiality and his sound judgement will be missed in Met O 10 and by the Office as a whole.

We wish him and Mrs McCaffery a very long and happy retirement.

A. C. HUGHES

OBITUARY

We regret to record the death on 23 June 1977 of Mr M. Tyrala, Assistant Scientific Officer.

Mr Tyrala was Polish by birth, and joined the Meteorological Office in May 1947 after serving in the wartime Polish Air Force. At the time of his death he was stationed at Linton-on-Ouse, North Yorkshire.

We regret to announce the death on 24 July 1977 of Mr M. H. Heard, Higher Scientific Officer, who was at the time Officer-in-Charge at Boscombe Down. Mr Heard joined the Meteorological Office as a Scientific Assistant in October 1957, was promoted to the grade of Assistant Experimental Officer in March 1967 and to Higher Scientific Officer in November 1971. During his career in the Office he was occupied in synoptic and forecasting work at a variety of outstations in the United Kingdom and also in West Germany.

It is with regret that we record the death of Mr J. F. Fisher, Senior Scientific Officer, on 5 August 1977.

Mr Fisher joined the Office on 1 April 1947 as Assistant Experimental Officer after wartime service in the Royal Air Force, where he had attained the rank of Flying Officer. In 1951 he transferred to the Colonial Service as Meteorological Officer to Nyasaland and rejoined the Office in 1955, being promoted to Senior Experimental Officer in 1956. Mr Fisher served in a variety of forecasting posts at home and overseas, on weather ships, and in the Meteorological Research Flight. At the time of his death he was working at the London Weather Centre.

CORRECTION

Meteorological Magazine, October 1977, page 319. In the last line of Table IV the term for $CO_2(2)$ should be prefixed by a minus sign.

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NOTICES

It is requested that all books for review and communications for the Editor be addressed to the Director-General, Meteorological Office, London Road, Bracknell, Berkshire, RG12 2SZ, and marked 'For Meteorological Magazine'.

The responsibility for facts and opinions expressed in the signed articles and letters published in this magazine rests with their respective authors.

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